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Osterweil et al.

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(54) **METHODS AND SYSTEMS FOR DOMAIN NAME DATA NETWORKING**

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(Continued)

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H04L 67/568 (2022.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04L 61/4511*** (2022.05); ***H04L 61/58*** (2022.05); ***H04L 67/568*** (2022.05); *H04L 63/126* (2013.01)

(58) **Field of Classification Search**
CPC ... H04L 61/4511; H04L 61/58; H04L 63/126; H04L 67/568
See application file for complete search history.

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Assistant Examiner — Patrick F Ngankam
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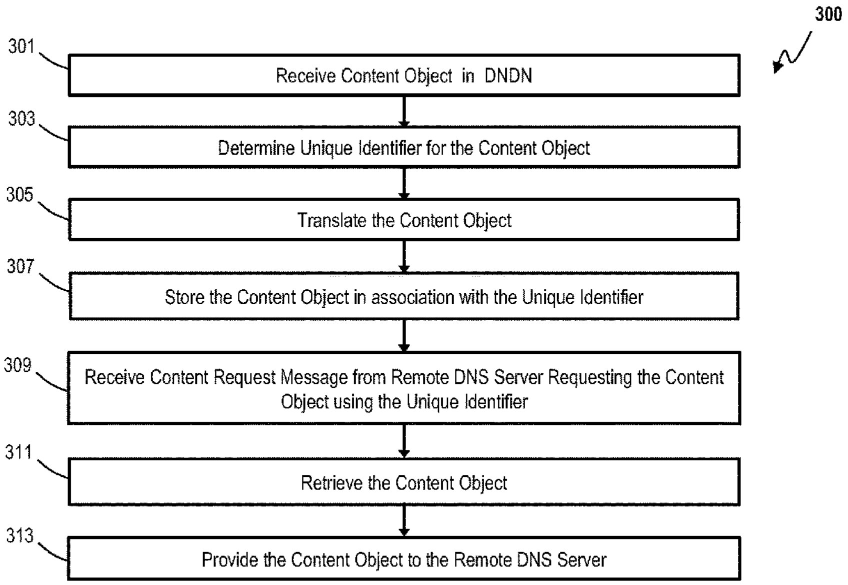
(57) **ABSTRACT**

Systems, devices and methods for a Domain Name Data Networking (DNDN) content delivery system are disclosed. Embodiments perform operations including obtaining a content object having a unique identifier. The operations also include storing a local instance of the content object in association with DNS resource records and the unique identifier. The operations further include providing the local instance of the content to a client in response to receiving a request from the client including the unique identifier.

20 Claims, 4 Drawing Sheets


300
301
Receive Content Object in DNDN
303
Determine Unique Identifier for the Content Object
305
Translate the Content Object
307
Store the Content Object in association with the Unique Identifier
309
Receive Content Request Message from Remote DNS Server Requesting the Content Object using the Unique Identifier
311
Retrieve the Content Object
313
Provide the Content Object to the Remote DNS Server

Related U.S. Application Data

(60) Provisional application No. 62/194,079, filed on Jul. 17, 2015.

(51) **Int. Cl.**

H04L 61/58	(2022.01)
H04L 9/40	(2022.01)

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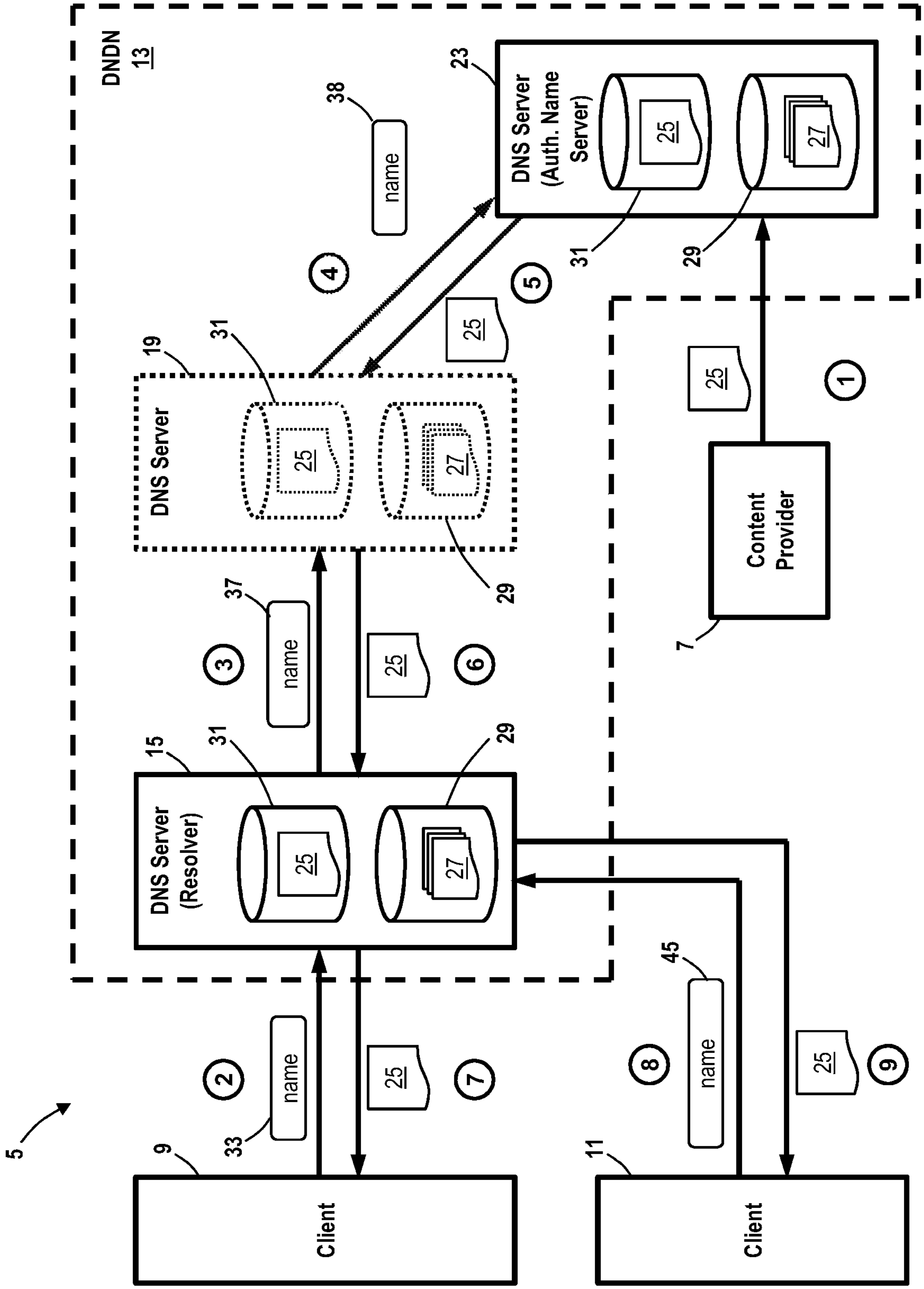
5
DNDN
13
Client
9
Client
11
DNS Server (Resolver)
15
DNS Server
19
DNS Server (Auth. Name Server)
23
Content Provider
7
name
33
name
37
name
38
name
45
25
27
29
31
1
2
3
4
5
6
7
8
9

FIG. 1

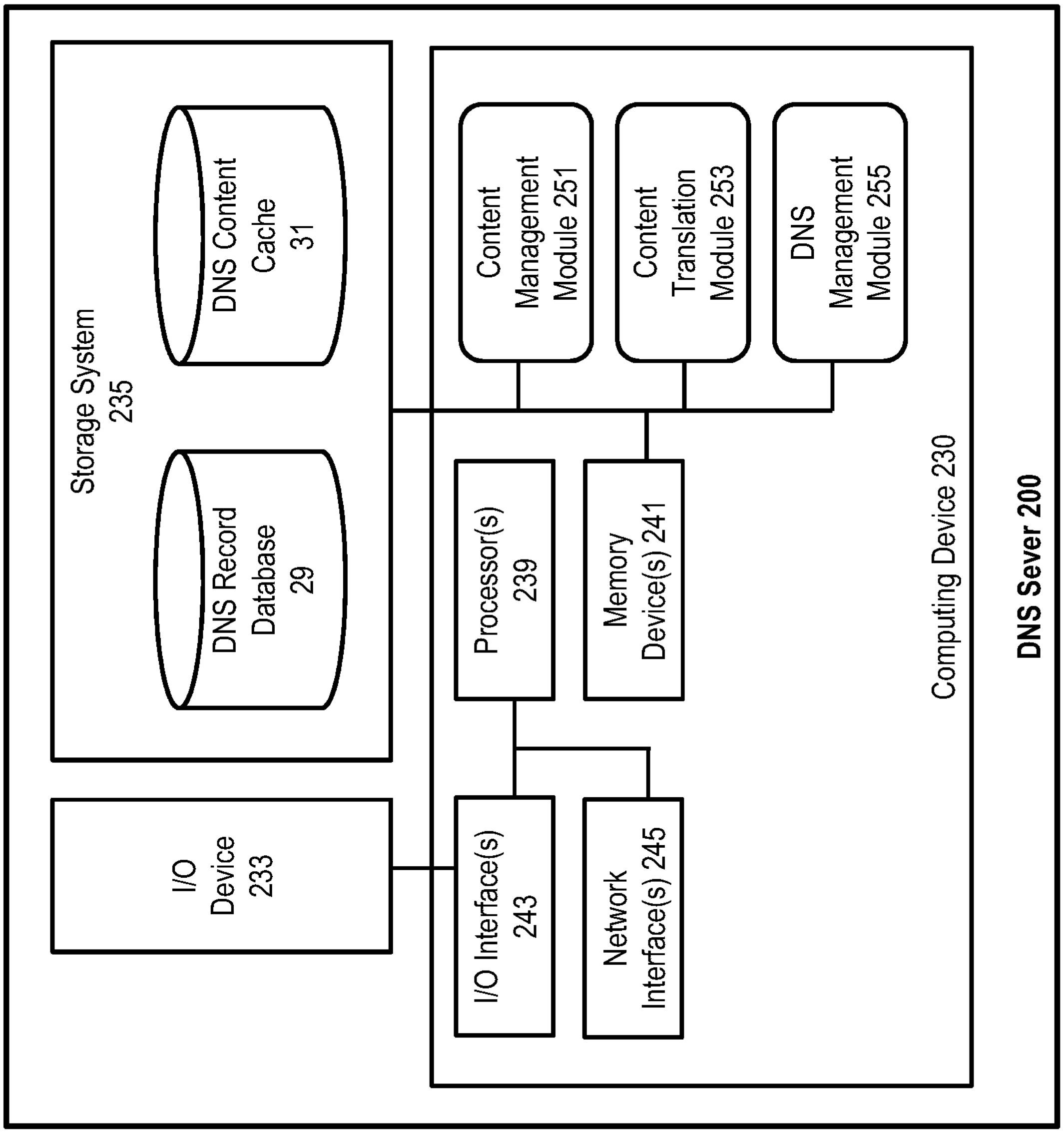
Storage System 235
DNS Record Database 29
DNS Content Cache 31
I/O Device 233
I/O Interface(s) 243
Network Interface(s) 245
Processor(s) 239
Memory Device(s) 241
Content Management Module 251
Content Translation Module 253
DNS Management Module 255
Computing Device 230
DNS Sever 200

FIG. 2

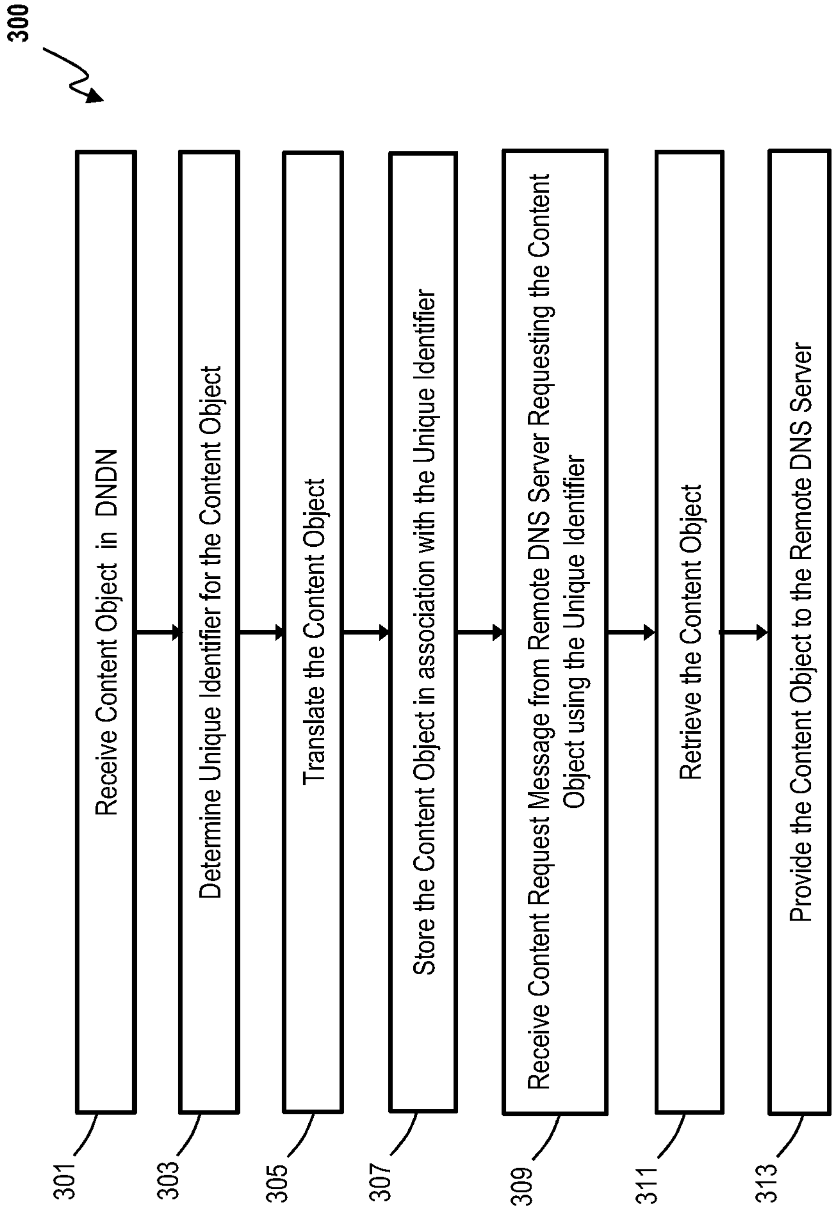
300
Receive Content Object in DNDN
301
Determine Unique Identifier for the Content Object
303
Translate the Content Object
305
Store the Content Object in association with the Unique Identifier
307
Receive Content Request Message from Remote DNS Server Requesting the Content Object using the Unique Identifier
309
Retrieve the Content Object
311
Provide the Content Object to the Remote DNS Server
313

FIG. 3

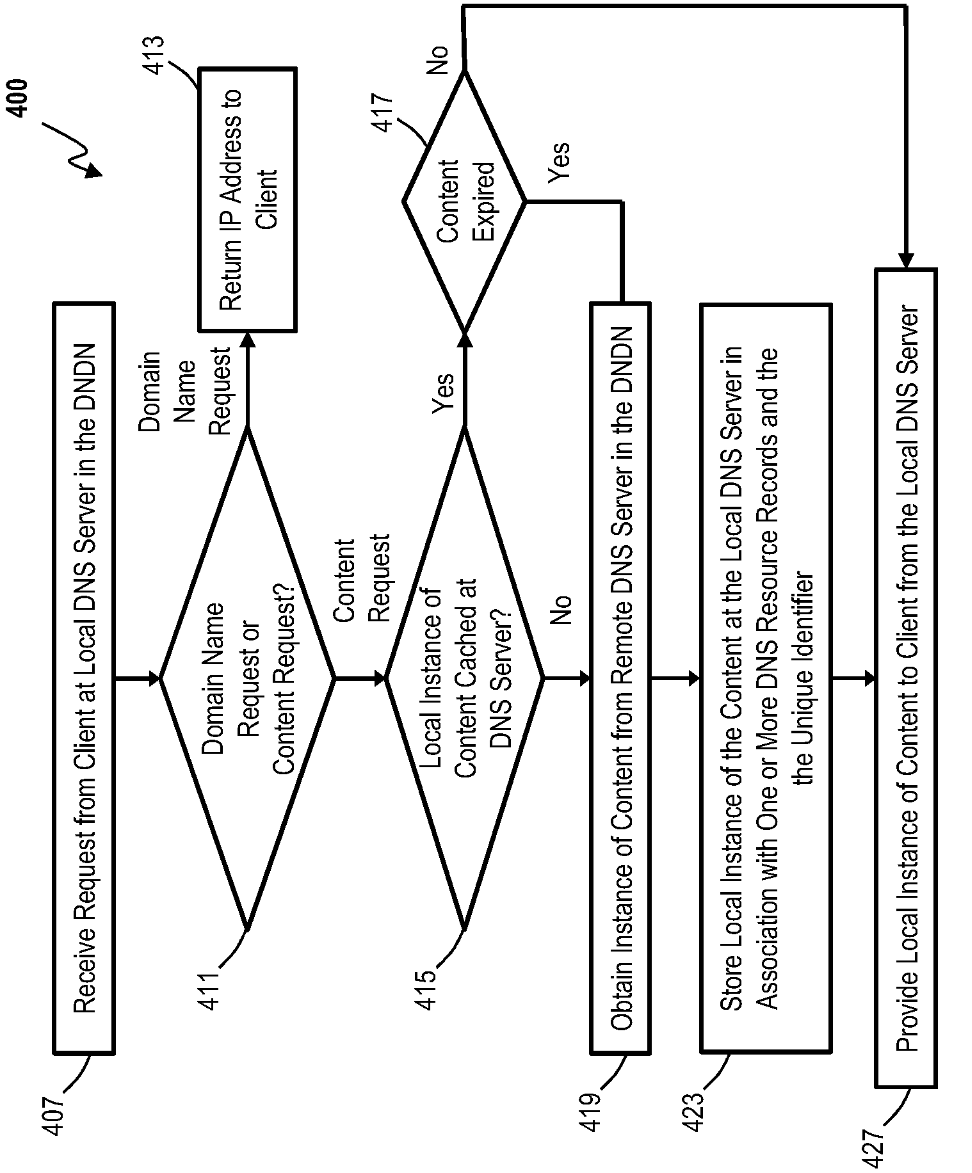
400
407
Receive Request from Client at Local DNS Server in the DNDN
411
Domain Name Request or Content Request?
Domain Name Request
413
Return IP Address to Client
Content Request
415
Local Instance of Content Cached at DNS Server?
Yes
417
Content Expired
Yes
No
No
419
Obtain Instance of Content from Remote DNS Server in the DNDN
423
Store Local Instance of the Content at the Local DNS Server in Association with One or More DNS Resource Records and the the Unique Identifier
427
Provide Local Instance of Content to Client from the Local DNS Server

FIG. 4

METHODS AND SYSTEMS FOR DOMAIN NAME DATA NETWORKING

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 15/147,387, filed May 5, 2016, which claims the benefit of U.S. Provisional Patent Application No. 62/194,079, filed Jul. 17, 2015, the disclosures of which are hereby incorporated by reference herein in their entirety.

BACKGROUND

The Domain Name System (DNS) is the part of the Internet infrastructure that translates human-readable domain names into the Internet Protocol (IP) numbers needed to establish TCP/IP communications over the Internet. That is, DNS allows users to refer to web sites, and other resources, using memorable domain names, such as "www.en.example.com," rather than the numeric IP addresses, such as "123.4.56.78," which are machine readable addresses used by software to communicate with computers on the Internet. Each domain name is made up of a series of character strings (labels) separated by dots. The right-most label in a domain name is known as the "top-level domain" (TLD). Examples of well-known TLDs are ".com," ".net," ".org." etc. Each TLD supports second-level domains, listed immediately to the left of the TLD, e.g., "example" in "www.example.com." Each second-level domain can support a number of third-level domains located immediately to the left of the second-level domain, e.g., "en" in "www.en.example.com." There can be additional level domains as well. For example, a domain with additional domain levels could be "www.landscape.photos.example.com."

A zone file is a text file that describes a portion of the DNS called a DNS zone. A zone file is organized in the form of resource records (RR) and contains information that defines mappings between domain names and IP addresses and other resources. The format of zone files is defined by a standard, with each line typically defining a single resource record. A line begins with a domain name, but if left blank, defaults to the previously defined domain name. Following the domain name is the time to live (TTL), the class (which is almost always "IN" for "internet" and rarely included), the type of DNS resource record (A, MX, SOA, etc.), followed by type-specific data such as the IPv4 address for A records. Comments can be included by using a semi-colon and lines can be continued by using parentheses. There are also file directives that are marked with a keyword starting with a dollar sign.

The DNS distributes the responsibility of assigning domain names and mapping those names to IP addresses by designating authoritative name servers for each domain. Authoritative name servers are assigned to be responsible for their particular domains, and in turn can assign other authoritative name servers for their sub-domains. This mechanism generally helps avoid the need for a single central register to be continually consulted and updated. The DNS resolution process allows for users to be directed to a desired domain by a reverse lookup process whereby the user enters the desired domain, and the DNS returns appropriate IP numbers. During the DNS resolution process, a request for a given domain name is routed from a resolver (e.g. a stub resolver) to an appropriate server (e.g. a recursive resolver) to retrieve the IP address. To improve efficiency, reduce DNS traffic across the Internet, and increase performance in end-user applications, the DNS supports DNS cache servers that store DNS query results for a period of time determined by the time-to-live (TTL) of the domain name record in question. Typically, such caching DNS servers, also called DNS caches, also implement the recursive algorithm necessary to resolve a given name starting with the DNS root through to the authoritative name servers of the queried domain. Internet service providers (ISPs) typically provide recursive and caching DNS servers for their customers. In addition, home networking routers may implement DNS caches and proxies to improve efficiency in the local network.

Information-centric networking is a general concept for proposed architectures for the Internet in which network names refer directly to content stored in the network (e.g. files) rather than referring to connection endpoints (e.g. servers). Named-data Networking (NDN) and Content-centric Networking (CCNx) are two dominant proposals for protocols to facilitate a reference information-centric network (ICN) architecture. As used herein, the term "ICN" refers to these reference architectures and similar proposals, and the term "information-centric networking" refers to the broader general concept.

An ICN network consists of routers, where each router has a cache that acts as a content store, and edge routers are connected to users and origin servers. The routers can provide content in response to interest packets, which encapsulate requests for content by its name. An origin server is a server that originates the content to be served in the ICN network, thus fulfilling requests of the interest packets. The content is returned in data packets that may or may not be cached in the ICN network. In ICNs, content is forwarded back to a user on the same path as it is requested by that user, and a PIT (pending interest table) at each ICN router records which each interest packet has been fulfilled. A face in ICN is the access point (e.g. a port) at which data is sent or received in a router. Notably, in ICN architectures, names of content maybe hierarchically structured. For example, video produced and published by a producer Example might be referred to as/ndn/com/Example/videos/demo.mpg, where "/" delimits name components.

Current ICN architectures have several design and deployment issues. First, they rely on caching among a dense population of ICN nodes. However, scant deployment of such ICN limits their availability to end users. Second, ICN architectures use an unstructured namespace in which names can be assigned to content by content providers. Doing so makes it challenging to disambiguate which provider is the authority for named content. Third, ICN architectures assume a data-centric security approach that attempts to ensure security through cryptographic signatures on all data packets. In particular, each data packet in ICN is signed by a producer's private key and signatures are verified by the potential consumer. But ICN does not have an architecture for securely discovering and verifying the authenticity of keys.

SUMMARY

In accordance with aspects of the present disclosure, systems, devices and methods for a Domain Name Data Networking (DNDN) content delivery system are disclosed. Embodiments of the systems, methods, and devices perform operations including storing, by a DNS server in the DNDN content delivery system, a local instance of a content object in association with DNS resource records identifying the

content object. The operations also include retrieving, by the DNS server, the local instance of the content object using the DNS resource records in response to a request from a client device identifying the first content object. The operations further include providing, by the DNS server, the local instance of the content to the client in response to the request.

DRAWINGS

The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1** illustrates a block diagram of an example of an environment for implementing systems and processes in accordance with aspects of the present disclosure;

FIG. **2** illustrates a system block diagram of an example server device in accordance with aspects of the present disclosure;

FIG. **3** illustrates a flow diagram of an example of a process in accordance with aspects of the present disclosure; and

FIG. **4** illustrates a flow diagram of an example of a process in accordance with aspects of the present disclosure.

DETAILED DESCRIPTION

The present disclosure is directed to content delivery in distributed information networks. Systems, methods, and computer-readable storage devices in accordance with aspects of the present disclosure provide a Domain Name Data Networking (DNDN) architecture that provides ICN architecture that uses the DNS to store and retrieve content by name, rather than by location. Content in the DNDN network is cached at DNS servers along with resource records to optimize performance and reduce latency. For example, when a user (e.g., consumer) requests content previously served to another user on the same network path or domain, the request can be fulfilled from a cache at a local DNS server (e.g., an edge node of the DNS), rather than a remote server that originally stored the content.

In an exemplary implementation of a DNDN network in accordance with the present disclosure, a content object (e.g., a document or media file) is initially located on a DNS zone's authoritative name server. The DNDN network can cache the content at the same DNS servers that cache resource records that map domain names with IP addresses. In embodiments, the DNS servers within the DNDN network are configured in the same way as primary caching DNS recursive resolvers, and augmented using other available caching recursive resolvers. Thus, when a particular content object is requested, the cache of the DNS recursive resolver is checked for the content object. If the content is not in the cache, the list of peer DNS caches is queried over DNS (e.g., with the Recursion Desired (RD) bit set to 0, which informs these peer nodes that the query should only be answered if it is already in cache). If none of the caches have the requested data, the primary caching recursive resolver is instructed to fetch it. In each case, the query can instruct caches to use DNSSEC (Domain Name System Security Extension) checking (e.g., by setting the DO bit), and optionally ask to have all verification information sent to the primary caching recursive resolver (e.g., by setting the CD bit). This allows the local cache to store content data for future provision to other servers and clients in the DNDN network by directly retrieving the content after the peers and clients have a cache miss.

Advantageously, embodiments of the DNDN network disclosed herein save substantial network overhead by reducing content fetching. Additionally, embodiments provide for name management, operational caching, routing, deployable security, and scalability for content using the DNS infrastructure. For example, some embodiments facilitate security by providing per-packet signing at the data producers and these signatures can be verified by the users (e.g., consumers). Moreover, embodiments use DNS SEC to provide operational secure key learning, source authenticity, integrity protection, and secure denial-of-existence of DNS data. Further, in embodiments content in the DNDN system can be stored and/or transported via the DNS using an existing DNS record type (e.g., a TXT record type, which DNS uses for transporting opportunistic encryption material, sender policy framework (SPF) material, and DNS service discovery material).

FIG. **1** illustrates a block diagram of an example of an environment **5** for implementing systems and processes in accordance with aspects of the present disclosure. The environment **5** includes a content provider **7**, client device **9**, client device **11**, and DNDN network **13**, which includes DNS servers **15**, **19**, and **23**. The content provider **7** can be any entity that generates or provides computer-readable and/or computer-executable content **25**. The content **25** can be one or more data files, including documents, images, videos, computer programs, etc.

In embodiments, client **9** and client **11** are each a device (e.g., a desktop computer or a mobile computing device) of a content consumer that requests content **25** provided by the content provider **7** to the DNDN network **13**. In embodiments, the clients **9** and **11** are servers that can be internal or external to the DNDN network **13**. For example, client **9** and/or client **11** can be stub resolvers having local caches that store the content **25**.

The DNDN network **13** is a DNS modified to store and deliver content in accordance with aspects of the present disclosure. The DNS servers **15**, **19**, and **23** can be name servers of the DNS that each store DNS resource records **27** in DNS record databases **29** (e.g., zone files) for resolving DNS queries. In some examples, the DNS server **15** can be a caching recursive resolver, the DNS server **19** can be a conditional forwarding server, and DNS server **23** can be an authoritative name server. Additionally, the DNS servers **15**, **19**, and **23** can each include DNS content caches **31** for storing content **25** in accordance with aspects of the present disclosure. As noted by the hashed-lines, in some embodiments, the DNS server **19** is optional and the DNS server **15** can communicate directly with DNS server **23**. It will be understood that the configuration and relationships of the servers **15**, **19**, and **23** within the DNDN network **13** illustrated in FIG. **1** are merely for the sake of example and that other configurations and relationships are within the scope of the present disclosure. For example, it is understood that the DNDN network **15** includes a greater number of servers **15**, **19**, and **23** arranged in additional layers or groupings within the DNDN network **15**. For example, the DNDN network **15** can include some or all of the components of the DNS.

The environment **5** illustrates a functional flow of an example process by which the clients **9** and **11** can obtain the content **25** using the DNDN network **13** in accordance with aspects of the present disclosure. Numeric elements (1) to (9) are provided to clarify the description of the process illustrated in FIG. **1**. Initially, the clients **9** and **11** and DNS servers **15** and **19** lack copies of the content **25**. At (1), the DNS server **23** in the DNDN network **13** can receive an instance of the content **25** from the content provider **7**. The DNS server **23** may store the content **25** in its DNS content cache **31**, which may be included in DNS server **23** or located remotely from DNS server **23**. In some embodiments, the DNS server **23** can segment the content **25** into a number of related DNS resource records such that the content **25** can be stored, retrieved, and shared in the same or similar manner as DNS resource records **27**. In other embodiments the content **25** is not segmented; rather, the DNS server **23** can store a single DNS resource record including a pointer to the content **25**.

At (2), the client **9** sends to the DNDN network **13** a content request message **33** requesting the content **25**. In embodiments, the content request message **33** is an ICN interest packet intercepted by the DNDN network **13** and routed to DNS server **15**. In accordance with aspects of the present disclosure, the content request message **33** identifies the content **25** by a name (e.g., "name") that is unambiguous and/or unique within the DNDN network **13**. From among the various servers of the DNDN **13**, the DNS server **15** can receive the content request message **33** based on its geographic or topological proximity to the client **9**. Based on the name included in the content request message **33**, the DNS server **15** can check the name space of its local DNS content cache **31** for the requested content **25**. In accordance with the present example, the DNS content cache **31** of DNS server **15** does not yet include an instance of the content **25** at (2). Instead, at this point in the exemplary process, the content **25** is only stored in the DNDN network **13** by DNS server **23**. Accordingly, the DNS server **15** attempts to resolve the content request message **33** within the DNDN network **13**. For example, the DNS server **15** can store information directing it to the DNS server **19** or the DNS server **23** based on information included in the content request message **33** (e.g., information identifying a domain of the DNS).

At (3) the DNS server **15** requests the content **25** from the DNDN network **13** by sending content request message **37**, including the name of the content **25**, to DNS server **19**, which can be the same or different than content message **33**. In embodiments, the DNS server **19** can be, for example, a forwarding server that forwards the content request message **37** to the DNS server **23** based on a DNS domain name specified in the content request message **37**. In embodiments, the DNS server **19** can check a name space of its local DNS content cache **31** for the requested content **25** prior to forwarding the content request. However, in accordance with the present example, the DNS content cache **31** of DNS server **19** does not yet include an instance of the content **25**.

At (4) the DNS server **19** requests the content **25** from the DNDN network by sending content request message **38**, including the name of the content **25**, to DNS server **23**. The content request message **38** can be the same or similar to content request message **37**. As noted above, the cache **31** of DNS server **23** contains the instance of the content **25**, which was provided by the content provider **7** at (1). After determining that its cache **31** contains the content **25** named in the content request **38**, at (5) the DNS server **23** responds to the content request message **38** by sending the content **25** to the DNS server **19**, which may store an instance of the content **25** in its cache **31**. And at (6), the DNS server **19** can respond to the query **37** by sending the content **25** to the DNS server **15**, which stores another instance of the content **25** in its cache **31**. At (7), the DNS server **15** responds to content request message **33** by sending the content **25** to the client **9**, which originally requested the content **25**. By the forgoing process, the DNS server **15** obtains an instance of the content **25** from DNS server **23** and stores it locally in its cache **31**.

After the content **25** is cached at the DNS server **15** (i.e., after (6) above), at (8) the client **11** (which may be a different entity than client **9**) can request the content **25** from the DNDN network **13** by sending a content request message **45**. The DNS server **15** receives message **45** and, based on the name included in the content request message **45**, the DNS server **15** can check the name space of its local DNS content cache **31** for the name of the requested content **25**. If an instance of the content **25** was previously stored in the cache **31** of the DNS server **15** at (6), and if the cached entry is still valid (i.e. the time-to-live has not expired), the DNS server **15** responds to the content request message **45** at (9) by sending an instance of the content **25** to the client **11**. Accordingly, the DNDN network **13** in accordance with the present disclosure greatly reduces the latency and network capacity required for the client **11** and subsequent clients to obtain the content **25**.

FIG. **2** illustrates a system block diagram of a DNS server **200** in accordance with aspects of the present disclosure. The DNS server **200** can be the same or similar to the DNS servers previously described herein (e.g., DNS servers **15**, **19**, and **23**, and in some embodiments, clients **9** and **11**). The DNS server **200** includes hardware and software that perform processes and functions described herein. In particular, the DNS server **200** includes a computing device **230**, an input/output (I/O) device **233**, and a storage system **235**. The I/O device **233** can include any device that enables an individual (e.g., a user) to interact with the DNS server **200** (e.g., a user interface) and/or any device that enables the computing device **230** to communicate with one or more other computing devices using any type of communications link. The I/O device **233** can be, for example, a touchscreen display, pointer device, keyboard, etc.

The storage system **235** can comprise a computer-readable, non-volatile hardware storage device that stores information and program instructions. For example, the storage system **235** can be one or more flash drives and/or hard disk drives. In accordance with aspects of the invention, the storage system **235** can store DNS record database **29** and DNS content cache **31**, which can be the same or similar to those previously described herein.

In embodiments, the computing device **230** includes one or more processors **239** (e.g., microprocessor, microchip, or application-specific integrated circuit), one or more memory devices **241** (e.g., RAM and ROM), one or more I/O interfaces **243**, and one or more network interfaces **245**. The memory device **241** can include a local memory (e.g., a random access memory and a cache memory) employed during execution of program instructions. Additionally, the computing device **230** includes at least one communication channel (e.g., a data bus) by which it communicates with the I/O device **233** and the storage system **235**. The processor **239** executes computer program instructions (e.g., an operating system and/or application programs), which can be stored in the memory device **241** and/or storage system **235**.

Moreover, the processor **239** can execute computer program instructions of a content management module **251**, a content translation module **253**, and a DNS management module **255**. In accordance with aspects of the present disclosure, the content management module **251** can interactively communicate with client devices (e.g., clients **9** and **11**) via a communication channel to receive requests (e.g., content request **33**) and provide content objects (e.g., content **25**). Additionally, the content management module **251** can interactively communicate with DNS servers (e.g., DNS servers **19**, and **23**) via a communication channel to request remote content objects (e.g., using content requests **37**, **38**) and store local instances (e.g., copies) in the DNS content cache **31**.

In accordance with aspects of the present disclosure, the content translation module **253** can translate content objects (e.g., content **25**) into DNS-compatible records for storage in the DNS content cache **31**, and retranslate to content objects back into for transmission to and/or use by end-users (e.g., clients **9** and **11**). In embodiments, the content translation module **253** segments content objects into a number a DNS-compatible files (e.g., resource records). For example, the content translation module **253** can segment a single audiovisual file (e.g., a MPEG file) into a number of related DNS resource records and store the DNS resource records in the DNS content cache such that they can be located and retrieved in a manner similar to domain name requests. In an exemplary implementation, a content object comprised of N bytes can be segmented into a number X of resource records, each of which includes a resource record type, a length, and an N/X byte segment of the content object. The content translation module can perform this process in reverse to retranslate the resource records back into the content object. Additionally, in accordance with aspects of the present disclosure, the DNS management module **255** performs functions of a conventional DNS server, such as maintaining a domain name registry (e.g., DNS resourced records **27**) in the DNS record database **31** and responding to DNS resolution queries as described previously herein.

It is noted that the computing device **230** can comprise any general purpose computing article of manufacture capable of executing computer program instructions installed thereon (e.g., a personal computer, server, etc.). However, the computing device **230** is only representative of various possible equivalent-computing devices that can perform the processes described herein. To this extent, in embodiments, the functionality provided by the computing device **230** can be any combination of general and/or specific purpose hardware and/or computer program instructions. In each embodiment, the program instructions and hardware can be created using standard programming and engineering techniques, respectively.

The flow diagrams in FIGS. **3** and **4** illustrate examples of the functionality and operation of a possible implementation of systems, devices, methods, and computer program products according to various embodiments of the present disclosure. Each block in the flow diagrams of FIGS. **3** and **4** can represent a module, segment, or portion of program instructions, which includes one or more computer executable instructions for implementing the illustrated functions and operations. In some alternative implementations, the functions and/or operations illustrated in a particular block of the flow diagrams can occur out of the order shown in FIGS. **3** and **4**. For example, two blocks shown in succession can be executed substantially concurrently, or the blocks can sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the flow diagram and combinations of blocks can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

FIG. **3** illustrates a flow diagram of an example of a process **300** in accordance with aspects of the present disclosure. At **301** a first DNS server (e.g., DNS server **23** executing content management module **251**) in a DNDN network (e.g., DNDN network **13**) receives a content object. The content object can be a portion of content (e.g., content **25**) or the entire content. The first DNS server can receive the content from a content provider (e.g., content provider **7**) or a proxy thereof. At **303**, the first DNS server determines a unique identifier (e.g., name) for the content object received at **301**. In accordance with aspects of the present invention, the unique identifier is unambiguous in the DNDN network. At **305** the first DNS server (e.g., executing translation module **253**) translates the content object received at **301** into a DNS-compatible record. In some embodiments, the first DNS server translates the content object by segmenting it into a number of related DNS resource records, as previously described herein. In other embodiments, the first DNS server translates the content object by associating it with a DNS resource record including a pointer to a storage location of the content object (e.g., in DNS content cache **31**). At **307** the first DNS server stores the content object translated at **305** with the unique identifier determined at **303**. At **309** the first DNS server receives a content request message (e.g., content request message **37**) from a remote DNS server (e.g., DNS server **15** or **19**) requesting the content object stored by the first DNS server at **307** using the same unique identifier as was determined at **303**. At **311** the first DNS server retrieves the content object requested at **309** based on the unique identifier. At **313** the first DNS server provides the content object to the remote DNS server in response to the request received at **309**. The remote DNS server can locally cache the content object by storing it as a DNS-compatible record, as previously described herein.

FIG. **4** illustrates a flow diagram of an example of a process **400** in accordance with aspects of the present disclosure. At **407**, a local DNS server (e.g., DNS server **15** executing content request module **251**) of a DNDN system (e.g., DNDN network **13**) receives a request (e.g., content request message **33**) from a client (e.g., client **9**). In accordance with aspects of the present disclosure, the request received at **407** can be either a domain name request or a content request (e.g., content request message **33**). As detailed previously herein, a content request includes a unique identifier that unambiguously identifies the requested content in the DNDN system. In embodiments, the name in the content request corresponds to a discrete item of content (e.g. content **25**), such as a document or media file, of which several instances may be stored (e.g., cached) in the DNDN system. Each instance of the content may have the same characteristics and parameters (e.g., size, author, provider, creation data, and/or time-to-live).

At **411** the local DNS server determines whether the request received at **407** is a domain name request or a content request. If it is determined at **411** that the request is a domain name request, then at **413** the local DNS server returns a DNS information (e.g. an IP address corresponding to the domain name from DNS record database **29**) in the conventional manner. If it is determined at **411** that the request is a content request, then at **415** the local DNS server determines whether an instance of the content specified by the name in the request is stored in its cache (e.g., in cache **31** of DNS server **15**). If the local DNS server determines that the content is stored in the cache (i.e., **415**, "Yes"), then at **417** the local DNS server determines whether the content stored in the cache is expired (e.g., based on time-to-live parameter stored in association with the requested content).

If it is determined at **417** that the content requested in **407** is not expired (i.e., **417**, "no"), then at **427**, the local DNS server provides the instance of the content from its cache to the client, and the process **400** ends. In some embodiments in which the client is an end user (e.g., a consumer at a personal computing device), content that has been translated into DNS-compatible records (e.g. in process **305**) is translated back to its original form (e.g. by content translation module **253**) before being provided to the client. In other embodiments in which the client is an end user, the content is provided to as DNS-compatible records and the client translates the content back to its original form using translation software (e.g., content translation module **253**). Further, in embodiments in which the client is a server (e.g., a stub resolver or an intermediate DNS server), the content can be stored locally in its translated form (e.g., in DNS content cache **31** as DNS-compatible records).

If at **415** the local DNS server determines that the content is not stored in the cache (i.e., **415**, "no"), or if at **417** that the content requested in **407** is expired (i.e., **417**, "yes"), then at **419**, the local DNS requests the content from the DNDN network (e.g., DNDN network **13**) by sending a content request message (e.g., content request messages **37**) including the unique name received at **407** to a remote DNS server (e.g., DNS server **19** or **23**) which may possess the content. In embodiments, the local DNS server resolves the location of the content in a manner that is the same or similar to recursively resolving an address in the DNS. Additionally or alternatively, the local DNS server resolves the location of the content by sending a content request message (e.g., content address message **37**) to a forwarding DNS server (e.g., DNS server **19**) which forwards the content address message to the second server (e.g., an authoritative name server, such as DNS server **23**) for a domain included in the content request. At **423** the local DNS server stores the instance of the content received at **419** in its cache. At **427**, the local DNS server provides an instance of content received at **419** to the client.

As detailed above, the processes **300** and **400** enable the DNDN network disclosed herein to efficiently identify and provide requested content to a client while, at the same time, caching a copy of the content at an edge of the DNDN system in DNS-compatible records. Thus, when a client (e.g., client **11**) subsequently requests the same content, it can be provided directly from the local DNS server at the edge of the DNDN system, which reduces latency and processing load throughout the DNDN system.

The foregoing description is illustrative, and variations in configuration and implementation may occur to persons skilled in the art. For instance, the various illustrative logics, logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor (e.g., processor **239**), an application specific integrated circuit, a field programmable gate array or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but, in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a microprocessor, a plurality of microprocessors, or any other such configuration.

In one or more exemplary embodiments, the functions described may be implemented in hardware, software, firmware, or any combination thereof. For a software implementation, the techniques described herein can be implemented with modules (e.g., procedures, functions, subprograms, programs, routines, subroutines, modules, software packages, classes, and so on) that perform the functions described herein. A module can be coupled to another module or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, or the like can be passed, forwarded, or transmitted using any suitable means including memory sharing, message passing, token passing, network transmission, and the like. The software codes can be stored in memory units (e.g., memory device **241**) and executed by processors. The memory unit can be implemented within the processor or external to the processor (e.g., processor **239**), in which case it can be communicatively coupled to the processor via various means as is known in the art.

If implemented in software, the functions may be stored on or transmitted over a computer-readable medium as one or more instructions or code. Computer-readable media includes both tangible, non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available tangible, non-transitory media that can be accessed by a computer. By way of example, and not limitation, such tangible, non-transitory computer-readable media can comprise RAM, ROM, flash memory, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, includes CD, laser disc, optical disc, DVD, floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Combinations of the above should also be included within the scope of computer-readable media.

Resources described as singular or integrated can in one embodiment be plural or distributed, and resources described as multiple or distributed can in embodiments be combined. The scope of the present teachings is accordingly intended to be limited only by the following claims. Although the invention has been described with respect to specific embodiments, those skilled in the art will recognize that numerous modifications are possible. For instance, the servers can have additional functionalities not mentioned herein. In addition, embodiments of the present disclosure can be realized using any combination of dedicated components and/or programmable processors and/or other programmable devices. While the embodiments described above can make reference to specific hardware and software components, those skilled in the art will appreciate that different combinations of hardware and/or software components can also be used and that particular operations described as being implemented in hardware might also be implemented in software or vice versa.

What is claimed is:

1. A Domain Name System (DNS) server comprising:

a processor;

a data storage device including:

a DNS resource record store that stores DNS resource records for resolving DNS queries, and a DNS content cache that stores one or more instances of content objects; and

program instructions stored on the data storage device that, when executed by the processor, control the DNS server to perform operations comprising:

obtaining a content object having a unique identifier;

translating the content object into at least one DNS-compatible record by segmenting the content object into one or more DNS-compatible resource records associated with the unique identifier;

storing, in the DNS content cache, the DNS-compatible resource records associated with the unique identifier;

receiving, from a client device, a content request that includes the unique identifier;

determining, based on the unique identifier received in the content request, one or more DNS-compatible resource records associated with the unique identifier;

based on the one or more DNS-compatible resource records, determining a storage location of an instance of the content object in the DNS content cache; and

providing, to the client device from the DNS content cache, the instance of the content object.

2. The DNS server of claim **1**, wherein the content object is comprised of N bytes, the segmenting comprising segmenting the content object into a number X of DNS-compatible resource records, each of which includes a resource record type, a length, and an N/X byte segment of the content object.

3. The DNS server of claim **2**, wherein providing the instance of the content object comprises retranslating the DNS-compatible resource records back into the content object.

4. The DNS server of claim **1**, wherein the content object is a DNS record.

5. The DNS server of claim **1**, wherein the content object is stored using an existing DNS record type.

6. The DNS server of claim **5**, wherein the existing DNS record type is a TXT record type that supports transporting opportunistic encryption material, sender policy framework material, and DNS service discovery material.

7. The DNS server of claim **1**, wherein the one or more DNS-compatible resource records comprise a pointer to the storage location of the instance of the content object in the DNS content cache.

8. The DNS server of claim **1**, wherein the unique identifier comprises a domain name, and wherein the content object comprises a resource record type.

9. A method comprising:

obtaining a content object having a unique identifier;

translating the content object into a Domain Name Service (DNS)-compatible record by segmenting the content object into DNS-compatible resource records associated with the unique identifier;

storing the DNS-compatible resource records associated with the unique identifier in a DNS content cache;

receiving a content request that includes the unique identifier;

determining, based on the unique identifier received in the content request, one or more DNS-compatible resource records associated with the unique identifier;

based on the one or more DNS-compatible resource records, determining a storage location of an instance of the content object in the DNS content cache; and

providing, to a client device from the DNS content cache, the instance of the content object.

10. The method of claim **9**, wherein the content object is comprised of N bytes, the segmenting comprising segmenting the content object into a number X of DNS-compatible resource records, each of which includes a resource record type, a length, and an N/X byte segment of the content object.

11. The method of claim **10**, wherein providing the instance of the content object comprises retranslating the DNS-compatible resource records back into the content object.

12. The method of claim **9**, wherein the content object is a DNS record.

13. The method of claim **9**, wherein the content object is stored using an existing DNS record type.

14. The method of claim **13**, wherein the existing DNS record type is a TXT record type that supports transporting opportunistic encryption material, sender policy framework material, and DNS service discovery material.

15. The method of claim **9**, wherein the one or more DNS-compatible resource records comprise a pointer to the storage location of the instance of the content object in the DNS content cache.

16. A method comprising:

receiving, at a local Domain Name Service (DNS) server in a domain name data networking (DNDN) system, a request from a client;

determining whether the request is a domain name request or a content request;

responsive to determining that the request is the content request, determining whether a local instance of a content object is cached at the local DNS server in the DNDN system;

responsive to determining that the local instance of the content object is cached at the local DNS server in the DNDN system, determining whether the local instance of the content object is expired; and

responsive to determining that no local instance of the content object is cached at the local DNS server in the DNDN system or responsive to determining that the local instance of the content object cached at the local DNS server in the DNDN system is expired:

obtaining an instance of the content object from a remote DNS server in the DNDN system,

storing the instance as the local instance of the content object at the local DNS server in the DNDN system in associated with one or more DNS resource records and a unique identifier, and

providing the local instance of the content object to the client from the local DNS server of the DNDN system.

17. The method of claim **16**, further comprising, responsive determining that the local instance of the content object is not expired, providing the local instance of the content object to the client from the local DNS server.

18. The method of claim **16**, further comprising, prior to receiving the request from the client:

translating the content object into a DNS-compatible record by segmenting the content object into DNS-compatible resource records associated with the unique identifier; and

storing the DNS-compatible resource records associated with the unique identifier in a DNS content cache of the local DNS server in the DNDN system.

19. The method of claim **18**, wherein providing the local instance of the content object to the client from the local

DNS server comprises retranslating the DNS-compatible resource records back into the content object.

20. The method of claim **16**, further comprising, responsive to determining that the request is the domain name request, providing an internet protocol (IP) address to the client from the local DNS server of the DNDN system.

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